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EVALUATION OF ANCHOR GROUTING AND BEARING PAD MATERIALS FOR USE IN TRANSMISSION LINE CONSTRUCTION AT LOW TEMPERATURES

FIELD EVALUATION OF ANCHOR GROUTS: PULLOUT TEST RESULTS

Report No. 89-129-K

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ABSTRACT

In 1987, a laboratory investigation was undertaken to assess anchor grouting materials, suitable for use at sub-freezing temperatures, for the construction of transmission lines. Part of this investigation included carrying out field trials (ie, rock anchor pullout tests), using the most promising grouts identified in the laboratory study. These pullout tests were conducted at a site near Lennox TGS. In this report, presented are the results from the pullout tests, including analyses and recommendations regarding the use of all the products that were tested.

The results from these pullout tests have already been utilized in producing an Ontario Hydro provisional specification entitled "Anchor Grouting in Rock or Concrete for Transmission Line Construction". This specification is currently being circulated for comments, before receiving final approval for corporate-wide use.

job	file	date	report no.
42-169-431 42-172-431 42-506-431	842.44(P)	June 19, 1989	89-129-K

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CONSTRUCTION AT LOW TEMPERATURES

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1.0 INTRODUCTION

In 1987, an investigation was undertaken to assess anchor grouting materials, suitable for use at sub-freezing temperatures, for the construction of transmission lines. The initial phase of the program involved a laboratory assessment of various proprietary polymer grouting materials. From this study, four materials were identified which demonstrated good potential for field applications/1/. These four materials were then subjected to full-scale rock anchor pullout tests in order to verify their in-situ performance. As well, "Anchortite 21-30 FS", a product that was approved for field use in a similar laboratory assessment program conducted in 1986/2/, and a Type 10 Portland cement grout were tested. These pullout tests were carried out at a site near Lennox TGS (see Figure 1). The purpose of this report is to present the pullout test results, including analyses and recommendations regarding the use of the products that were tested.

The results from these pullout tests have already been utilized in producing an Ontario Hydro provisional specification entitled "Anchor Grouting in Rock or Concrete for Transmission Line Construction"/3/. This specification is currently being circulated for comments, before receiving final approval for corporate-wide use. Therefore, this report is being produced as a matter of record, so that all results and analyses can be documented here in one reference.

2.0 OVERVIEW OF THE PROGRAM

The entire test program was subdivided into three distinct operations, that of drilling the anchor holes, installing (grouting) the anchors, and conducting the actual pullout tests. A complete record of the first two operations, including a general overview of the program, the procedures followed, and observations made during the drilling and grouting work, are contained in Reference 4. For the purposes of continuity, however, pertinent aspects of the program will be repeated here.

The pullout tests were conducted using 35 mm (1-3/8 in.) diameter, 827 MPa (120 ksi) yield strength, Dywidag deformed bars grouted in rock to nominal depths of 305 mm (12 in.), 508 mm (20 in.), and 915 mm (36 in.). Each hole diameter was 57 mm (2-1/4 in.), and was drilled with an impact rotary drill equipped with a Star bit. A list of the grouts that were tested is provided in Table 1, and in Table 2 is a summary matrix of the pullout tests that were conducted.

A total of 46 anchors were installed. They were arranged in 5 rows spaced 6.1 m (20 ft.) apart, with the spacing within each row being variable. These variable spaces were calculated assuming an inverted right angle rock failure cone for each embedment. A sketch illustrating the layout and identification of each anchor is given in Figure 2.

Since these tests were designed to assess each grout's performance, failure of the anchor rod or rock was not desired. To prevent rod failure, high strength (827 MPa, 120 ksi) deformed bars were used. These bars have surface deformations conforming to ASTM A 615 (ie, that of standard reinforcing), and therefore, the development of bond will be similar to that of regular reinforcing bars. In an attempt to preclude rock failure, the anchor holes were to be drilled 254 mm (10 in.) deeper than the required embedment depth. Therefore, for a 305 mm (12 in.) embedment, the holes were drilled to a nominal depth of 559 mm (22 in.) and only the bottom 305 mm (12 in.) of the hole was filled with grout. Similarly, for the embedment depths of 508 mm (20 in.) and 915 mm (36 in.), the holes were to be drilled 762 mm (30 in.) and 1168 mm (46 in.), respectively. Information regarding the exact drilled depths of the holes, the grouted lengths of the anchors, and the particular grout used for each is given in Tables 3, 4 and 5.

Another important aspect of the field trials was comments made by members of the construction crew regarding the handling and use of each material. These comments are presented in Reference 4.

3.0 THEORETICAL DISCUSSION

As discussed in Section 2.0, these pullout tests were designed to assess each anchor grout's pullout capacity, and as such, of the four possible modes of failure (ie, rod, rock uplift, grout-to-rod bond, grout-to-rock bond), it is the grout-to-rod bond and grout-to-rock bond failures that were of primary interest. Therefore, before the tests were conducted, preliminary theoretical

calculations for each failure mode were made. The following is a summary of the calculations:

i) Anchor Rod Failure

The yield stress of deformed bars typically used for anchor bolts is 414 MPa (60 ksi), whereas, for these tests, deformed bars with a yield stress of 827 MPa (120 ksi) were used. The rationale for this choice is that if an anchor installation could sustain a load greater than the yield load or ultimate load of a 35 mm (1-3/8 in.) diameter, 414 MPa (60 ksi) deformed bar, then by using high strength bars (ie, 827 MPa, 120 ksi), either load could be applied without ever exceeding the capacity of the anchor or coupling hardware.

note: -for a 35 mm (1-3/8 in.) diameter, 414 MPa (60 ksi) bar:

-the nominal yield load is 396 kN (89.1 kip)

-the nominal ultimate load is 594 kN (133.7 kip)

-for a 35 mm (1-3/8 in.) diameter, 827 MPa (120 ksi) bar:

-the nominal yield load is 801 kN (180 kip)

-the nominal ultimate load is 991 kN (222.7 kip)

Therefore, loads as high as 801 kN (180 kips) were applied (to installations that could sustain such loads) without fear of failing the anchor rod.

ii) Grout-to-Rod Bond Failure

This failure mechanism is typically the least critical of all failure modes (except for rod failure) in most installations/5/. Previous tests conducted at the Sir Adam Beck Generating Station and elsewhere have shown that the ultimate grout-to-rod (deformed) bond failure stress can be predicted by the following formula/6/:

Ultimate grout-to-rod bond stress (psi) = $11.5 \sqrt{U.C.S.}$

where U.C.S. = unconfined compressive strength of the grout (psi)

This formula was derived on the basis of testing cement-based grouts. If, however, the unconfined compressive strengths of the polymeric materials that were tested in this program are substituted in the formula, and based upon the nominal embedment lengths, the range of expected failure loads due to grout-to-rod bond failure were calculated as follows:

-for the 305 mm (12 in.) embedments: 200-298 kN (45-67 kips)

-for the 508 mm (20 in.) embedments: 334-498 kN (75-112 kips)

-for the 915 mm (36 in.) embedments: 600-898 kN (135-202 kips)

Appendix A contains all information used to perform these calculations, as well as, results specific to each product.

iii) Grout-to-Rock Bond Failure

An empirical relationship originally proposed by Littlejohn and Bruce /7/ for this failure mode is:

$$\text{Ultimate grout-to-rock bond stress} = \frac{\text{U.C.S.}}{10}$$

where U.C.S. = unconfined compressive strength of the rock
or grout (whichever is smaller)

This relationship is based on the assumption that the uplift load is resisted by a uniformly distributed stress acting along the entire grout-to-rock interface. Extensive tests previously conducted by the Research Division have shown that this formula is generally adequate for predicting grout-to-rock bond failure loads /5,8/.

For this program, the unconfined compressive strength of the rock was 90 MPa/9/ and the unconfined compressive strength of the grouts ranged between 39 and 88 MPa. Therefore, in all calculations, it was the unconfined compressive strength of the grouts that governed, resulting in a range of predicted failure loads as follows:

- for the 305 mm (12 in.) embedments: 214-480 kN (48-108 kips)
- for the 508 mm (20 in.) embedments: 358-800 kN (80-180 kips)
- for the 915 mm (36 in.) embedments: 644-1440 kN (144-324 kips)

Appendix B contains all information used to perform these calculations, as well as, results specific to each product.

iv) Rock Uplift

Rock uplift loads were calculated by assuming that, upon failure, an inverted cone of rock is pulled out of the rock mass. The apex of the cone is assumed to be at the bottom of the anchor with a contained angle of 90°. Uplift resistance is provided by the rock's shear strength on the cone's surface plus the weight of the rock mass contained within the cone.

Tests previously conducted near the site of the present pullout tests (ie, near Lennox TGS) indicate that the rock in this area has a relatively poor shear strength with an average value of only 65 kPa (9.5 psi)/5/. Therefore, in order to develop a larger mass of rock, resulting in greater uplift failure loads, each anchor hole was drilled 254 mm (10 in.) deeper than the actual grouted length of the anchors (see Section 2.0 for complete details). The resulting calculated rock uplift failure loads are as follows:

- for the 305 mm (12 in.) embedment: 95 kN (21.3 kips)
- for the 508 mm (20 in.) embedment: 179 kN (40.2 kips)
- for the 915 mm (36 in.) embedment: 405 kN (91.1 kips)

Theoretical failure loads for all possible modes of failure are summarized in Table 6. From this table, it is clear that even after taking the precaution of drilling each hole 254 mm (10 in.) deeper than required, rock uplift was still potentially the most critical failure mode. Therefore, it was decided, that if rock failure could not be avoided, to a high degree of confidence, then steps should be taken to monitor this type of failure. This decision led to the installation of additional instrumentation known as "telltales". Telltales are small diameter rods installed to various depths in the rock at various distances from an anchor. If rock uplift occurs, vertical movement of each telltale would be detected with electronic displacement probes. Telltales were installed for 20 of the 46 anchors, and a complete description of this type of instrumentation, as well as, an overview of the entire test setup, is given in Section 4.0.

4.0 TEST SETUP

4.1 Loading Arrangement

The loading system is schematically illustrated in Figure 3. Since all anchors protruded only approximately 200 to 250 mm (8 to 10 in.) above the rock surface, 3 m (10 ft.) long, reusable, extension rods were attached to each anchor prior to loading. The extension rods were 35 mm (1-3/8 in.) diameter, 827 MPa (120 ksi) Dywidag reinforcing thread bar, and the attachment was made with high strength Dywidag coupling nuts. Load was then applied to each anchor with a 900 kN (100 ton) capacity hollow ram hydraulic jack supported on a bearing plate that straddled a pair of 9 m (30 ft.) long steel beams. The beams, which were W27 x 94 sections, were in turn supported on H-pile bearing pads. The clear span between the bearing pads was 6.2 m (20 ft.). This distance ensured that there was no interference from the bearing pads if rock uplift failure occurred. This distance also accommodated the testing of more than one anchor (ie, 2 or 3) for each setup of the steel beams and bearing pads. For example, the beams could be set up directly over three 305 mm (12 in.) deep anchors, and the hydraulic jack simply had to be moved along the beam to test each anchor (see Figure 3). Similarly, two 508 mm (20 in.) deep or two 915 mm (36 in.) deep anchors could be tested from one test setup. Thus, the beams and bearing pads did not have to be repositioned 46 times to test all 46 anchors. A photo showing the typical test setup is given in Figure 4.

4.2 Instrumentation

The instrumentation consisted of a 900 kN (100 ton) load cell to monitor the applied loads and various displacement probes to monitor the vertical uplift of the anchor rod, grout column, rock surface, and sub-surface rock mass. The load cell was installed between the top of the hollow ram jack and the high strength coupling nut (see Figure 3). The displacement probes were attached to a stationary reference located beneath the beams. This reference, referred to as a "batterboard", was a 104 x 52 mm (4 x 2 in.) steel hollow section that was oriented perpendicular to the steel beams, and was supported on timber piles placed at a minimum distance of 6.2 m (20 ft.) apart. All output from

the instruments was monitored with a computer-based data acquisition system. The output from the load cell and the displacement probe that monitored the anchor rod uplift was also plotted autographically during each test.

The minimum amount of instrumentation for each test consisted of using the load cell and four displacement probes. These instruments were used as follows:

- i) The load cell was used to monitor the applied load.
- ii) One displacement probe was used to monitor the anchor rod uplift by monitoring the relative movement between a reference point, which was clamped to the anchor, and the batterboard (see Figure 5).
- iii) One displacement probe was used to monitor the uplift of the grout column. During anchor installation (grouting), a small diameter steel rod with a target on its upper end had been embedded in the grout column. The probe monitored the upward movement of this target, and hence the movement of the grout column (see Figure 5).
- iv) Two displacement probes were used to monitor the uplift of the surface of the rock. These probes were typically located from 150 to 300 mm (6 to 12 in.) on opposite sides of the anchor (see Figure 5).

As discussed in Section 3.0, additional instrumentation, which consisted of displacement probes and telltales, was utilized for 20 of the 46 anchors. Also as described, telltales are small diameter steel rods with targets on their upper end that were installed to various depths in the rock at various distances from the anchor. The actual depths that each telltale was to be installed was dependent on the assumed size and depth of the rock failure cone. The apex of the rock failure cone was assumed to be at the bottom of the anchor with a contained angle of 90° . Some telltales were installed to a depth below the theoretical failure cone and some telltales were installed such that they were within the cone (see Figure 6). Telltales were installed for the anchors designated as 1, 5, 8, 11, 14, 16, 18, 20, 22, B, 25, 27, 28, 30, 31, 33, 35, 37, 39, and C (see also Figure 2). Figure 6 illustrates the nominal depths and locations for each telltale, and Figure 7 is a photo showing a typical field setup of the telltales installed for a 508 mm deep anchor.

5.0 RESULTS

Generally, the grouts performed very well, and the sub-surface rock performed exceptionally well. Of the 46 anchors tested, there were only three premature rock uplift failures. Theoretical failure loads for all possible modes of failure are summarized in Table 6, and Table 7 is a summary of the average failure or sustained loads for all products, at each depth. Appendix C contains a complete summary of the results for each individual anchor installation.

Listed below are specific results and comments. When reading these comments, a key point is that 827 MPa (120 ksi) yield stress bars were used so that loads, which may have been as high as those equivalent to the yield load or ultimate load of a 414 MPa (60 ksi) bar, could be applied without fear of yielding or rupturing the actual anchor or coupling hardware (see Section 3.0).

a) For the 305 mm embedments

- i) The anchors grouted with LT Anchor, Concessive 2010/2020 and Type 10 cement all sustained loads, at failure, that were greater than the nominal yield load of a 414 MPa (60 ksi) anchor rod. The anchors grouted with Lokset and Anchortite 21-30 FS developed 91% of the nominal yield load, and it is expected that the anchors grouted with Pronto 12 would have sustained far greater loads than the 61% of the nominal yield load, which they did carry, had premature rock failure not occurred. The rock failure in these three anchors was due to voids in the rock layers that allowed a bulb of grout to form at approximately midlength of each grouted length (see Figure 8). The measured diameter of the Pronto 12 grout column was 57 mm (2-1/4 in.), whereas the bulb of grout had an average diameter of 90 mm (3-1/2 in.). Undoubtedly, the bulb acted as a wedge that developed a much shallower rock cone than that which was assumed in the original calculations.
- ii) The anchors grouted with Lokset, Anchortite 21-30 FS and LT Anchor failed due to grout-to-rock bond failure. Typical grout-to-rock bond failures are shown in Figure 9. Concessive 2010/2020 and Type 10 cement failed by grout-to-rod bond failure, and as discussed previously, the anchors grouted with Pronto 12 failed due to rock uplift.
- iii) In Figure 10 are load-displacement curves typical for an anchor that failed by grout-to-rock bond failure. Notable in this figure is that the upward movements of the anchor rod (D1) and the grout column (D2) were similar, while all telltales (D3, D4, D7, D8) in the rock moved less than 0.5 mm at failure. The actual anchor that is shown in this figure is one that had been grouted with Lokset.
- iv) In Figure 11 are load-displacement curves typical for an anchor that failed by grout-to-rod bond failure. Notable in this figure is that the upward movement of the grout column (D2), at failure, did not follow the upward movement of the anchor rod (D1). The telltales (D5, D6) remained essentially stationary. The actual anchor that is shown in this figure is one that had been grouted with Concessive 2010/2020.
- v) In Figure 12 are load-displacement curves typical for an anchor that failed due to rock uplift. The notable aspect in these curves is that the telltales that were located within the theoretical cone of failure (D3, D4) moved substantially more than those telltales located below the failure cone (D7, D8). The actual anchor that is shown in this figure is one that had been grouted with Pronto 12.

b) For the 508 mm embedments

- i) Of the seventeen anchors tested at this embedment depth, only four installations failed. However, all recorded average loads were well in excess of the nominal rupture load of a 35 mm (1-3/8 in.) diameter, 414 MPa (60 ksi) anchor (see Table 6 and 7).
- ii) The products that did fail were Lokset and Anchortite 21-30 FS. Two of three anchors grouted with each of these products failed due to grout-to-rock bond. Notably, these are the same products (except Pronto 12) that had the lowest failure loads in the 305 mm (12 in.) embedments.
- iii) In an attempt to fail the other thirteen installations, the maximum loads were maintained for 5 to 10 minutes. If creep was evident during the hold, the maximum loads were then cycled up to an additional five times. No additional failures were caused by this procedure; however, the creep of Concompressive 2010/2020 at the peak loads was greater than those of the other products. It is felt that this high creep led to the failure of one of the 915 mm (36 in.) deep anchors that had been grouted with this product (see next Subsection).

c) For the 915 mm embedments

- i) Of the twelve anchors tested at this embedment, only one installation failed. However, as for the 508 mm (20 in.) embedments, all recorded average loads were well in excess of the nominal yield and rupture load of an equivalent 414 MPa (60 ksi) anchor rod (see Tables 6 and 7).
- ii) As previously discussed, the anchor that did fail had been grouted with Concompressive 2010/2020. This failure was in the grout-to-rod bond, and occurred after approximately 5 minutes at a sustained load of 801 kN (180 kips).
- iii) In Figure 13 are load-displacement curves typical of an anchor installation that did not fail. The rod and grout column displacements were essentially linear and all sub-surface telltales were stable. The actual anchor that is shown in this figure is one that had been grouted with LT Anchor.

6.0 DISCUSSION

As part of the evaluation of these polymer anchor grouts, one of the objectives was to assess the applicability, to polymer grouts, of Brown's design formula for the ultimate grout-to-rod bond stress /6/ (see also Section 3.0). This assessment was deemed important as Brown's formula is provided as guidance in Ontario Hydro's Transmission Design Specification, No. 23, entitled "Foundation Design - Anchorage In Rock and Concrete"/10/. Additionally, this formula had been originally derived from field anchor pullout results using cementitious grouts. Therefore, when this program was designed, the 305 mm (12 in.) and 508 mm (20 in.) embedments were chosen on the basis that the theoretical calculations indicated that, aside from premature rock uplift, each installation at these depths would fail due to

grout-to-rod bond (see Table 6). This failure was also calculated to occur before the full yield load of a 35 mm (1-3/8 in.) diameter, 414 MPa (60 ksi) bar was developed. The full nominal yield load of a 414 MPa (60 ksi) bar was expected to be sustained in the 915 mm (36 in.) embedments. Now as indicated in Section 4.0, all anchor grouts performed far better than anticipated (ie, calculated). Of the 46 anchors tested, only six failed by grout-to-rod bond, thirteen by grout-to-rock bond and three due to premature rock uplift. Additionally, the loads sustained by the anchors embedded to 508 mm (20 in.) were all in excess of the nominal yield load of a 414 MPa (60 ksi) bar. Clearly, therefore, the failure loads calculated with Brown's formula were conservative for all grouts. Also, due to an insufficient number of data points (ie, failures) for grout-to-rod bond, similiar relationships (as Brown's) could not be developed for the polymer grouts.

One material that is questionable for use is Concessive 2010/2020. From a load carrying point of view, this product performed as well as the other products. However, it was found that this anchor grout exhibited very high creep prior to failure, as in the case of the 308 mm (12 in.) embedments, or when sustaining very high loads, as in the case of the 508 mm (20 in.) and 915 mm (36 in.) embedments. In fact, one anchor embedded 915 mm (36 in.) failed due to creep (see Section 4.0 and Appendix C). It is felt that the presence of moisture in the drilled holes prior to grouting caused this poor performance. All anchor holes had damp walls, and in a few cases, free water had to be removed from the bottom of the hole. Since absolutely dry conditions cannot be guaranteed in field applications, this product is not recommended for use. Additionally, Concessive's poor performance in the presence of moisture had been partially evident in the earlier laboratory studies/1/. In dry conditions, this product performed well, but in wet or damp conditions, pullout strength was often reduced. Therefore, the field trials served to confirm this problem, as well as, provide an insight as to the mechanism (ie, creep) that leads to Concessive's poor performance in the presence of moisture.

Another concern that is actually a result from a separate program, but should be mentioned here, is that the products Lokset and Anchortite 21-30 FS should not be used for anchor grouting in concrete. Generically, these products are polyesters and previous research has indicated potential for hydrolytic instability in high pH environments, which would be encountered in concrete/1/. The results from this other research have shown that samples of Lokset and Anchortite 21-30 FS immersed in caustic soda solutions undergo significant increases in weight and length as compared to the other products. Realistically, this environment is extremely severe; however, until further data are available, it is recommended that Lokset and Anchortite 21-30 FS be restricted from use in concrete.

Although these tests were not designed to test the sub-surface rock, two general comments can be made. From one anchor that did not fail (ie, anchor 40), an equivalent rock shear stress was calculated. Based upon an assumed 90° inverted rock cone at failure, the rock shear strength is estimated to be in excess of 120 kPa (17.4 psi). A value of 65 kPa (9.5 psi) had been used in the preliminary calculations (see Section 3.0). It should be noted, however, that when calculating the shear strength of 120 kPa (17.4 psi), account was

not made for the soil overburden. This overburden varied in depth between 203 mm (8 in.) and 610 mm (24 in.). The second comment is that for the anchors that failed by grout-to-rock bond, calculations using the formula proposed by Littlejohn and Bruce/7/ (see also Section 3.0) appear adequate. The products Lokset, Anchortite 21-30 FS and LT Anchor failed in grout-to-rock bond at the 305 mm (12 in.) embedment, and Lokset and Anchortite 21-30 FS failed as such at the 508 mm (20 in.) embedment. In only one of these five possible comparisons, of actual average to predicted grout-to-rock bond stress failure loads, was the formula unconservative. In this case (Anchortite 21-30 FS at 305 mm (12 in.)), the actual failure load was overestimated by 18%. In all other cases, the actual pullout loads were an average of 1.5 times greater than the predicted grout-to-rock bond failure loads.

In summary, it is felt that design guidance from formulas by Brown and by Littlejohn and Bruce, for calculating ultimate grout-to-rod bond stress and ultimate grout-to-rock bond stress, respectively, can be referred to when using these polymer grouts. This recommendation is made, however, with one restriction. This restriction is that the maximum value of unconfined compressive strength, which is required in each formula, be limited to 30 MPa (4500 psi) when using polymer grouts. Due to the very high actual unconfined compressive strengths of the polymers, there is a danger that unconservatively short embedment lengths may be calculated when using these formulas. Further, in this program, only one nominal anchor rod yield stress was assumed, and only one anchor rod diameter was tested. Now while these tests clearly confirmed the satisfactory behaviour of the polymers, until further testing (ie, additional bar diameters etc.), for design purposes, the polymers should be considered only as good as a good quality (ie, 30 MPa, 4352 psi) cement-based grout.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations that can be drawn from this test program are summarized as follows:

- i) Three new products listed below are recommended as anchor grouts for use in transmission line construction at sub-freezing temperatures.

-	LT Anchor Grout	(Cappar Limited)
-	Pronto 12	(Sika Canada Limited)
-	Lokset	(Fosroc)
- ii) Anchortite 21-30 FS, a product previously approved for use /11/, was tested for comparison purposes. This product again performed satisfactorily, and its continued use is recommended. This recommendation, however, is made pending the resolution of a problem, regarding the supply of this product (see Reference 12 for further details).
- iii) Concessive 2010/2020 is not recommended for use due to its variable performance in the presence of water.

- iv) Type 10 Portland cement grout ($w/c=0.4$) was also tested for comparison purposes. All approved products (ie, see (i) and (ii) above) performed favourably as compared to the cement grout.
- v) Lokset and Anchortite 21-30 FS should not be used for anchor grouting in concrete.
- vi) Present design guidelines that are followed to calculate required embedment lengths for anchors can be referred to when using these polymer grouts. If these formulas require a value of unconfined compressive strength, an upper limit of 30 MPa (4500 psi) should be used. This restriction essentially imposes a minimum embedment length if the polymer grout has a strength in excess of 30 MPa (4500 psi).

8.0 ACKNOWLEDGEMENTS

The principal funding for this study as provided by the the Transmission Lines Programs and Design Departments is gratefully acknowledged. As well, the assistance of Messrs. G. Senkiw, D. King and D. Austin of the Mechanical Research Department, who provided the instrumentation and load application for the pullouts, is acknowledged. The contribution of the Engineering and Technical Support staffs of both the Soils Sciences and Concrete Technology Sections during various stages of the planning and field work is also appreciated.

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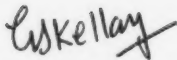
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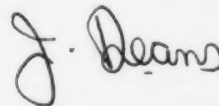


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9. Rankin, R.A., McKay, D.A., "Lennox GS - Boreholes For Rock Anchor Test Site", Ontario Hydro Research Division Report No. SR88-3-H, April 29, 1988, 3 pp.
10. Sato, J.A., Andre, H., "Transmission Tower Foundation Design: A Review of Concrete Anchor Bolting", Ontario Hydro Research Division Report No. 88-9-H, June 21, 1988, 49 pp.
11. Deans, J.J., Senkiw, G.A., "Field Evaluation of Low Temperature Anchor Grouts for Use in Transmission Line Construction", Ontario Hydro Research Division Report No. S85-11-H, August 20, 1985, 28 pp.
12. Memorandum, J.J. Deans to J.D. Forsyth, April 12, 1989, File 842.44(T).

TABLE 1**GROUTS**

GROUT TYPE	PRODUCT NAME	SUPPLIER
Modified Polyester/ Acrylate	Pronto 12	Sika Canada Limited
Vinyl Ester	LT Anchor Grout	Cappar Limited
Polyester	Lokset	Fosroc
Methyl Methacrylate	Concressive 2010/2020	Adhesive Engineering
Polyester	Anchortite 21-30 FS	Celtite
Cement	Type 10 Portland Cement (W/C = 0.4)	Laboratory Standard

TABLE 2**SUMMARY OF PULLOUT TESTS**

PRODUCT	NO. OF TESTS AT EACH EMBEDMENT		
	305 mm	508 mm	915 mm
Pronto 12	3	3	2
LT Anchor Grout	3	3	2
Lokset	3	3	2
Concressive 2010/2020	3	3	2
Anchortite 21-30 FS	3	3	2
Type 10 Portland Cement (W/C = 0.4)	2	2	2

TABLE 3
INFORMATION FOR ANCHORS GROUTED TO A
NOMINAL EMBEDMENT OF 305 mm

ANCHOR I.D.	PRODUCT	HOLE DEPTH (mm)	DISTANCE BETWEEN TOP OF ROCK AND GROUT (mm)	GROUTED LENGTH (mm)
1	PRONTO 12	533	273	260
2		552	311	241
3		546	292	254
4	LOKSET	572	267	305
5		559	260	299
6a		540	241	299
7	ANCHORTITE 21-30 FS	559	254	305
8		546	216	330
9		565	260	305
10	LT ANCHOR	578	235	343
11		528	210	318
12		533	203	330
13	CONCRESSIVE 2010/2020	546	165	381
14		514	203	311
15		540	229	311
A	TYPE 10 CEMENT	597	279	318
B		584	254	330

NOTES:

- 1) The diameter of all holes was 57 mm (2-1/4 in.).
- 2) The length of all anchor rods used for these pullouts was 711 mm (28 in.).
- 3) The diameter of the anchor rod was 35 mm (1-3/8 in.).

TABLE 4

**INFORMATION FOR ANCHORS GROUTED TO A
NOMINAL EMBEDMENT OF 508 mm**

ANCHOR I.D.	PRODUCT	HOLE DEPTH (mm)	DISTANCE BETWEEN TOP OF ROCK AND GROUT (mm)	GROUTED LENGTH (mm)
16	PRONTO 12	762	241	521
17		749	241	508
18		749	203	546
19	LOKSET	743	203	540
20		724	229	495
21		749	241	508
22	ANCHORTITE 21-30 FS	718	235	483
23		718	235	483
24		743	235	508
25	LT ANCHOR	724	241	483
26		724	241	483
27		762	235	527
28	CONCRESSIVE 2010/2020	762	235	527
29		750	248	502
30		743	222	521
E	TYPE 10 CEMENT	699	159	540
F		775	305	470

NOTES:

- 1) The diameter of all holes was 57 mm (2-1/4 in.).
- 2) The length of all anchor rods used for these pullouts was 915 mm (36 in.).
- 3) The diameter of the anchor rod was 35 mm (1-3/8 in.).

TABLE 5
INFORMATION FOR ANCHORS GROUTED TO A
NOMINAL EMBEDMENT OF 915 mm

ANCHOR I.D.	PRODUCT	HOLE DEPTH (mm)	DISTANCE BETWEEN TOP OF ROCK AND GROUT (mm)	GROUTED LENGTH (mm)
31	PRONTO 12	1137	210	927
32		1149	216	933
33	LOKSET	1149	235	914
34		1143	229	914
35	ANCHORTITE 21-30 FS	1162	305	857
36		1156	191	965
37	LT ANCHOR	1143	229	914
38		1143	216	927
39	CONCRESSIVE 2010/2020	1118	191	927
40		1111	178	933
C	TYPE 10 CEMENT	1098	260	838
D		1149	279	870

NOTES:

- 1) The diameter of all holes was 57 mm (2-1/4 in.).
- 2) The length of all anchor rods used for these pullouts was 1321 mm (52 in.).
- 3) The diameter of the anchor rod was 35 mm (1-3/8 in.).

TABLE 6
SUMMARY OF THEORETICAL FAILURE LOADS

Product	FAILURE LOAD (kN)											
	305 mm EMBEDMENT				508 mm EMBEDMENT				915 mm EMBEDMENT			
	ROD	GROUT-ROD	GROUT-ROCK	ROCK	ROD	GROUT-ROD	GROUT-ROCK	ROCK	ROD	GROUT-ROD	GROUT-ROCK	ROCK
PRONTO 12	991	292	458	95	991	487	762	179	991	875	1373	405
LOKSET	991	200	214	95	991	334	358	179	991	600	644	405
ANCHORTITE 21-30 FS	991	283	426	95	991	470	709	179	991	845	1277	405
LT ANCHOR GROUT	991	298	480	95	991	498	800	179	991	898	1440	405
CONCRESSIVE 2010/2020	991	208	233	95	991	347	388	179	991	524	698	405
TYPE 10 CEMENT (W/C = 0.4)	991	251	339	95	991	419	566	179	991	755	1019	405

NOTES:

- (i) ROD = rod failure load.
GROUT-ROD = grout-to-rod bond failure load.
GROUT-ROCK = grout-to-rock bond failure load.
ROCK = rock uplift failure load.
- (ii) Anchor rod diameter is 35 mm (1-3/8 in.).
- (iii) The anchor rod failure value of 991 kN is based on an ultimate stress of 1034 MPa (150 ksi).
- (iv) Commonly used anchor rod has a nominal yield and ultimate stress of 414 MPa (60 ksi) and 621 MPa (90 ksi), respectively.
The nominal yield and ultimate loads of a commonly used (414 MPa, 60 ksi) 35 mm (1-3/8 in.) diameter anchor rod are 396 kN (89 kips) and 594 kN (180 kips), respectively.

TABLE 7
PULLOUT RESULTS

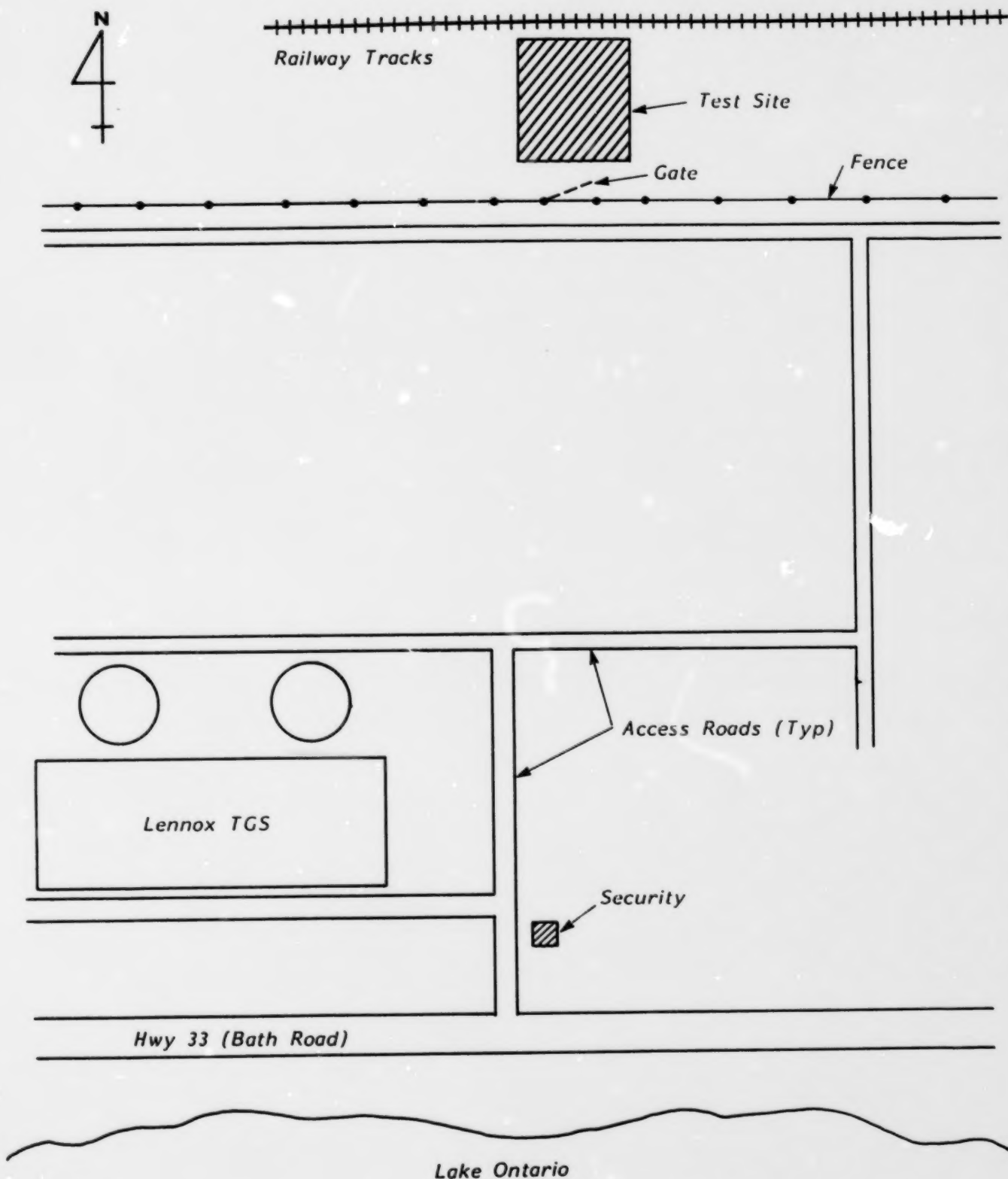
MATERIALS	305 mm EMBEDMENT ⁽¹⁾		508 mm EMBEDMENT ⁽¹⁾		915 mm EMBEDMENT ⁽²⁾	
	AVERAGE LOAD (kN)	FAILURE MODE/ COMMENTS	AVERAGE LOAD (kN)	FAILURE MODE/ COMMENTS	AVERAGE LOAD (kN)	FAILURE MODE/ COMMENTS
PRONTO 12	245	- rock uplift - each grout column had a bulb (ie, a large increase in diameter at mid length)	734 ⁽³⁾	- no failures	667 ⁽³⁾	- no failures
LOKSET	360	- grout/rock bond - grout column uniform	684	- grout/rock bond - grout column uniform - one anchor did not fail at 734 kN	667 ⁽³⁾	- no failures
ANCHORTITE 21-30 FS	360	- grout/rock bond - grout column uniform - one anchor failed at 89 kN; not included in average	712	- grout /rock bond - grout column uniform - one anchor did not fail at 734 kN	667 ⁽³⁾	- no failures
LT ANCHOR	645	- grout/rock bond - grout column uniform	734 ⁽³⁾	- no failures	734 ⁽³⁾	- no failures
CONCRESSIVE 2010/2020	467	- grout/rock bond - rod pulled out and grout column remained in hole	778 ⁽³⁾	- no failures	801 ⁽⁴⁾	- no failure in one anchor rod at 801 kN - one anchor pulled out and grout remained in hole at 801 kN
TYPE 10 CEMENT (W/C = 0.4)	681	- grout/rod bond - rod pulled out and grout column remained in hole	734 ⁽³⁾	- no failures	734 ⁽³⁾	- no failures

(1) Three anchors grouted with each product (except Type 10 cement). Two anchors grouted with Type 10 cement.

(2) Two anchors grouted with each product.

(3) This is the maximum load before the test was terminated. The test was terminated due to a concern with yielding the pullout hardware (ie, coupler nuts, extension rod).

(4) These were the last anchors tested. Therefore, the maximum load was increased to the nominal yield load (801 kN) of the pullout hardware (ie, coupler nut, extension rod).

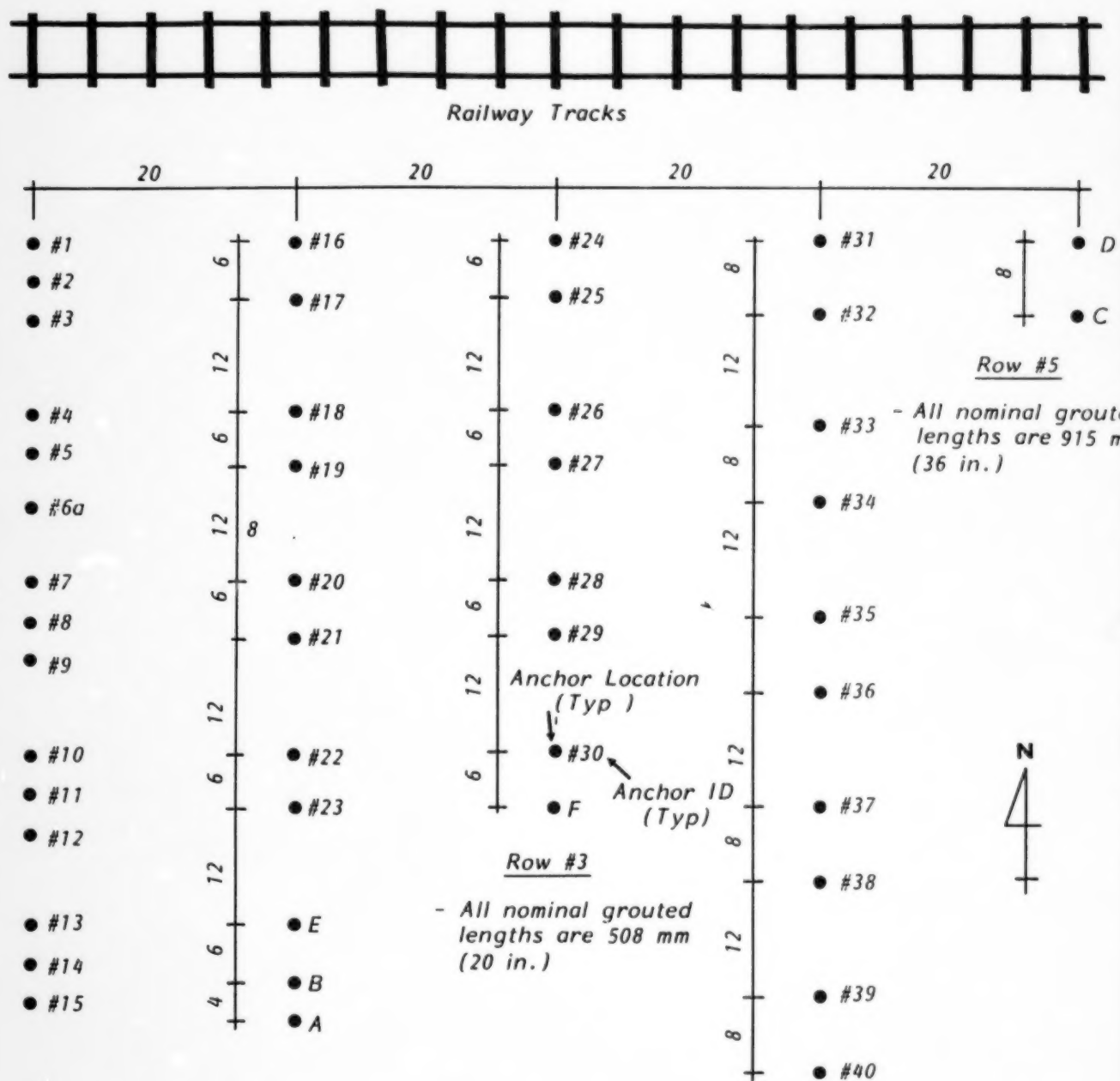


NOTE:

(1) Sketch not to scale.

FIGURE 1
TEST SITE LOCATION
 - 19 -

89-129
 179733-RD



Row #1

- All nominal grouted lengths are 305 mm (12 in.)

Row #2

- All nominal grouted lengths, except holes 'A' & 'B', are 508 mm (20 in.)

- 'A' & 'B' nominal grouted lengths are 305 mm (12 in.)

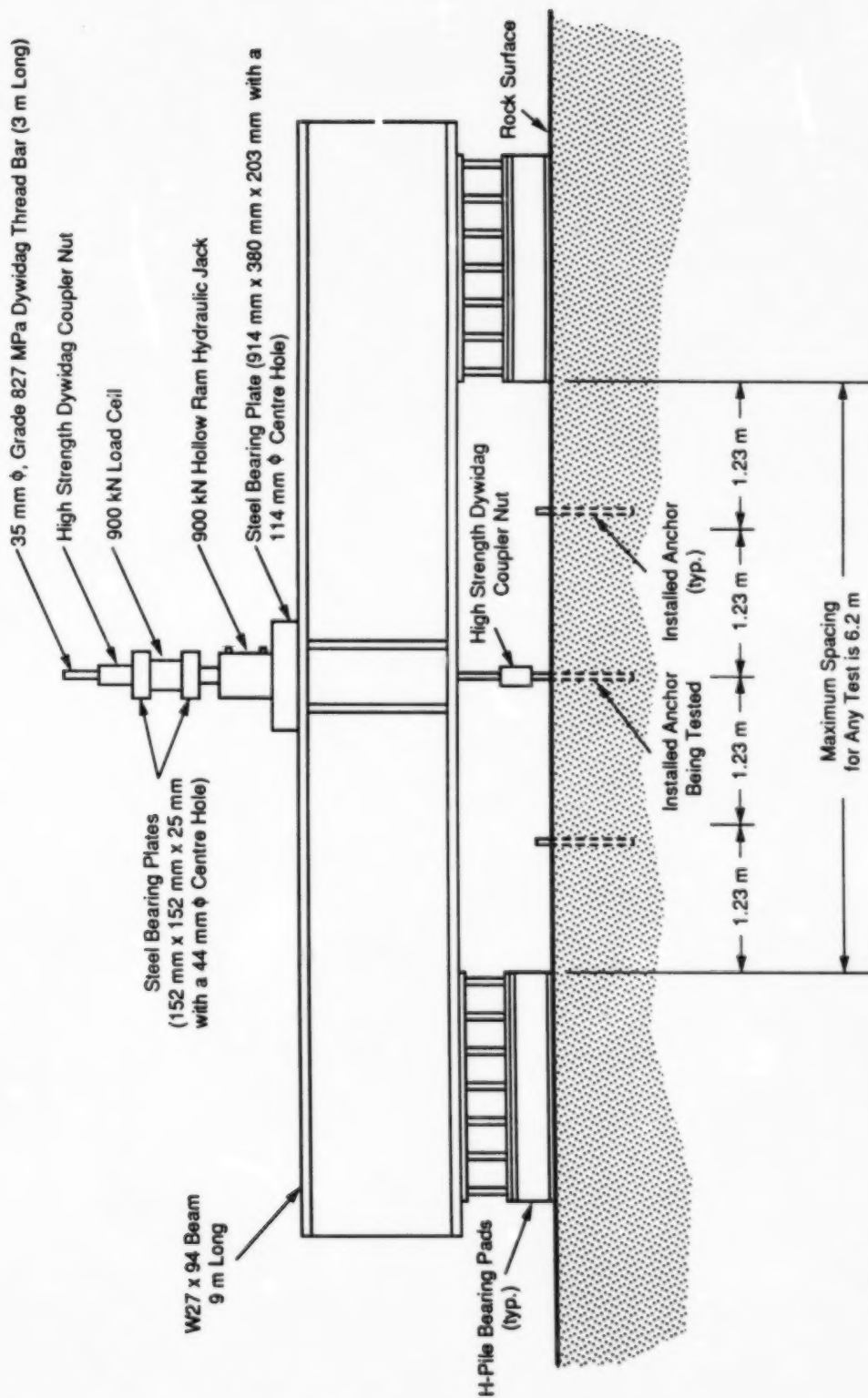
Row #4

- All nominal grouted lengths are 915 mm (36 in.)

NOTES:

- (1) All dimensions are in feet unless otherwise noted.
- (2) Sketch not to scale.

FIGURE 2
ANCHOR LAYOUT



NOTES:

(i) The total clear space (4.9 m) between H-pile bearing pads that is illustrated in this Figure is typical of that used for the 305 mm deep anchors.

(ii) See Figure 5 for a sketch of the displacement probe instrumentation.

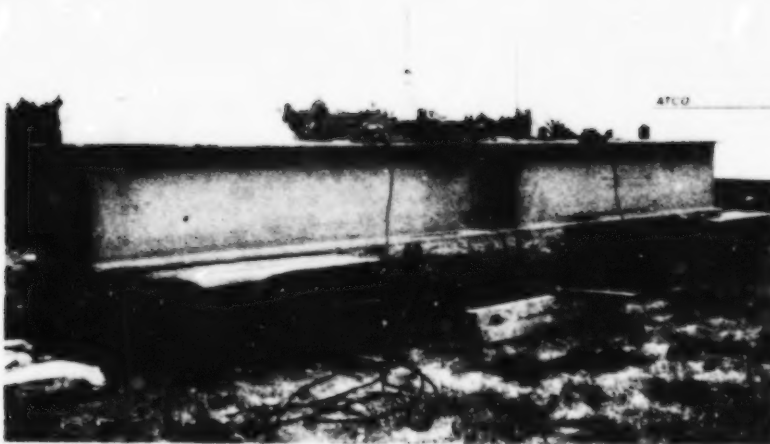
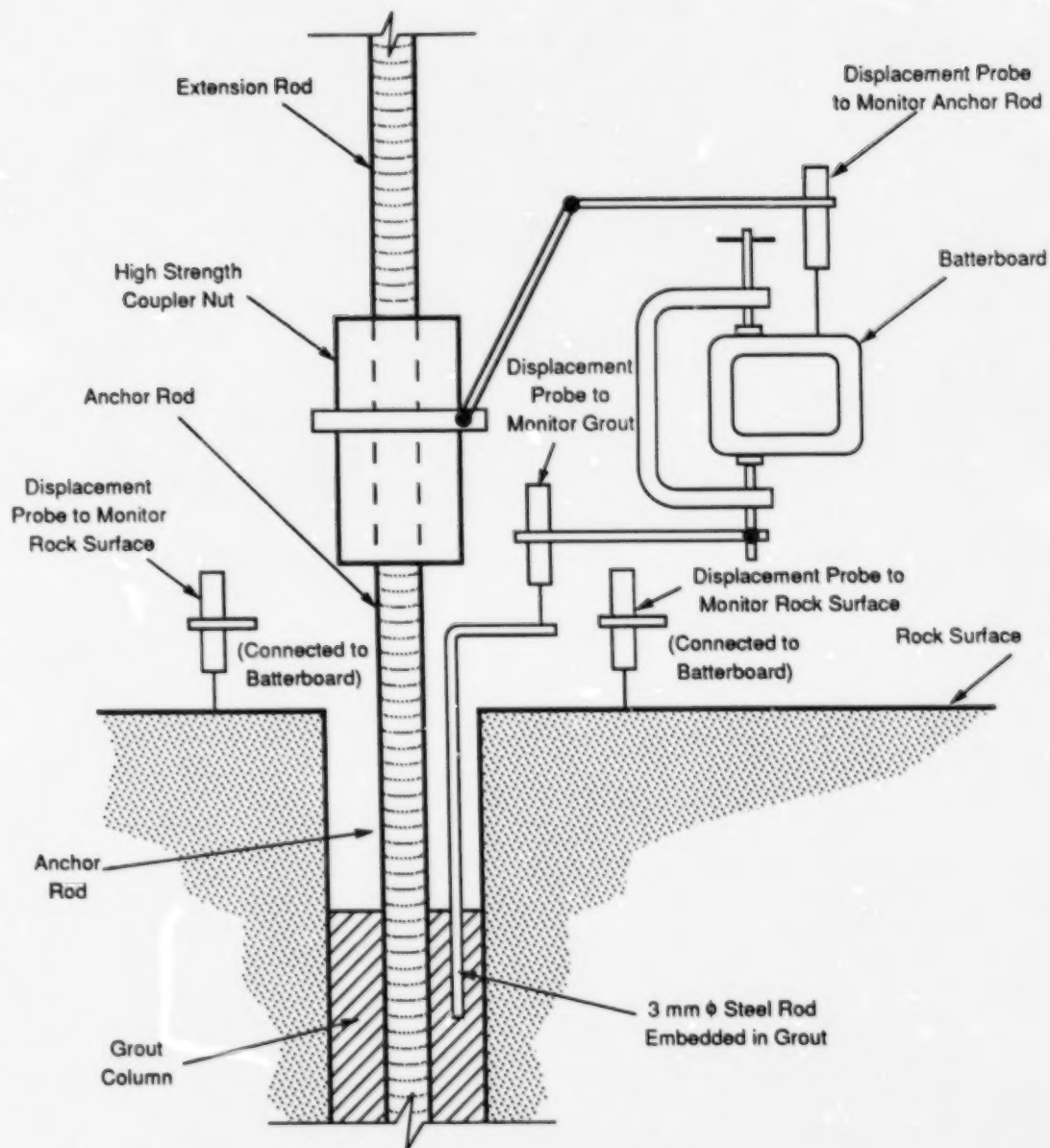


FIGURE 4
TYPICAL TEST SETUP

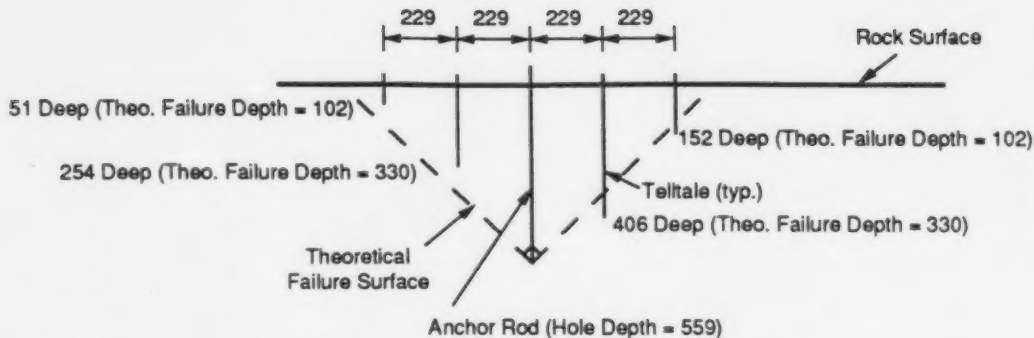


NOTES:

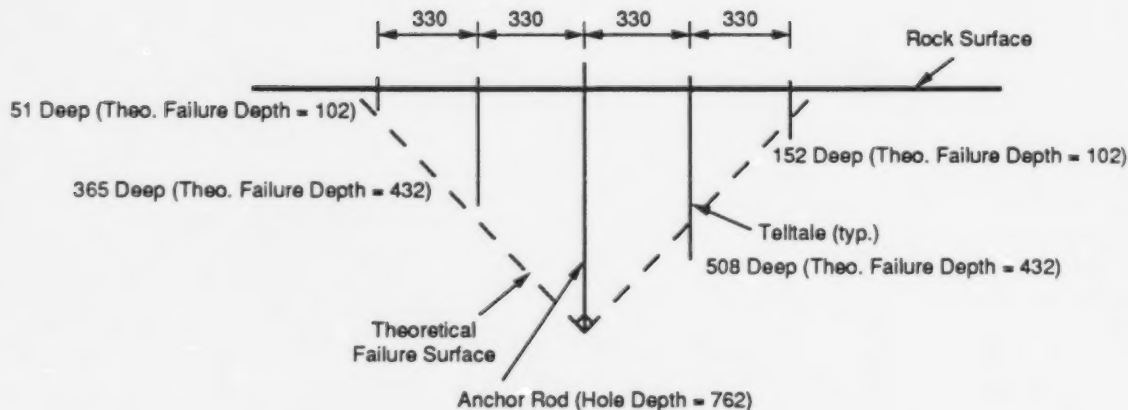
- (i) Illustrated are the minimum number of displacement probes used for each test.
- (ii) See Figure 6 for layout of displacement probes used to monitor the telltales.

FIGURE 5

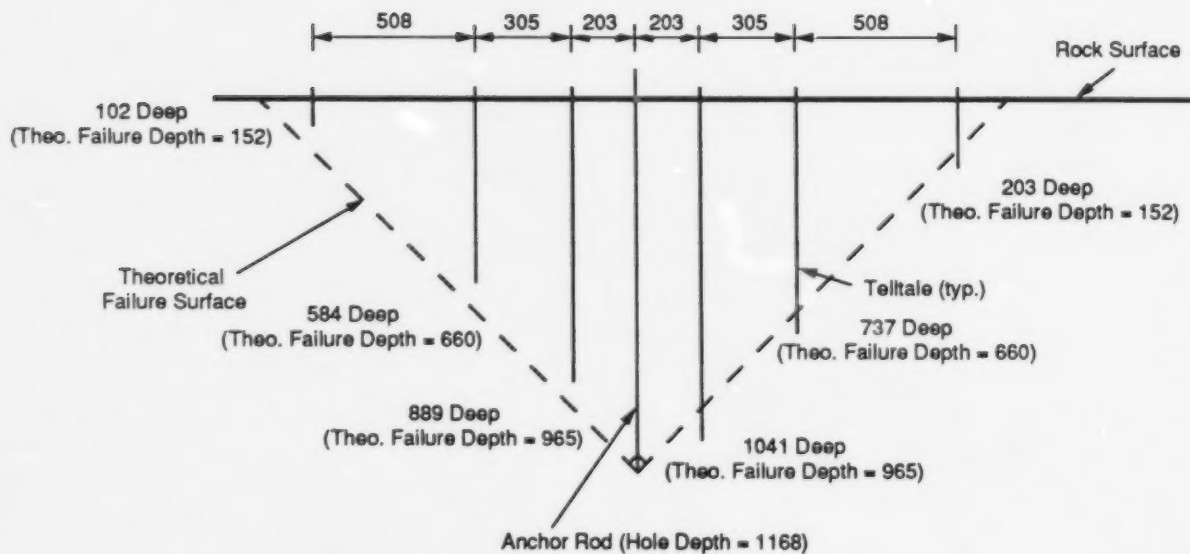
LAYOUT OF DISPLACEMENT PROBES



(a) Telltale Installation For 305 mm Deep Anchors



(b) Telltale Installation For 508 mm Deep Anchors



(c) Telltale Installation For 915 mm Deep Anchors

NOTE: All dimensions in mm.

FIGURE 6

LAYOUT OF TELLTALES

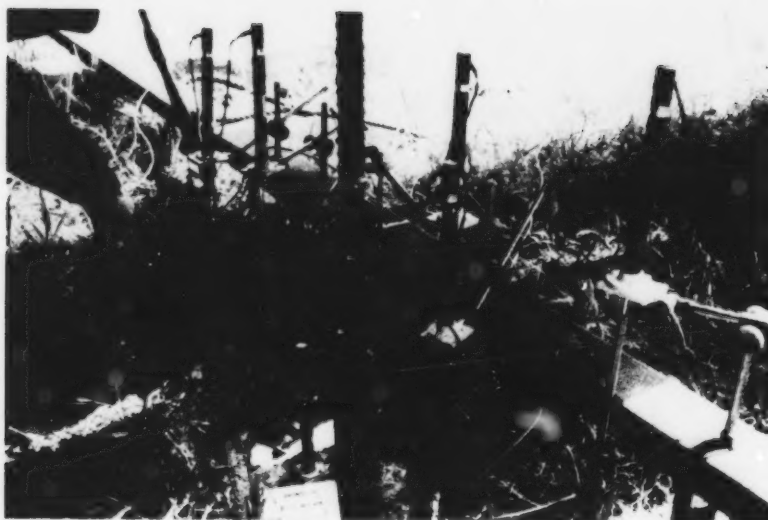


FIGURE 7
TYPICAL TELLTALE SETUP

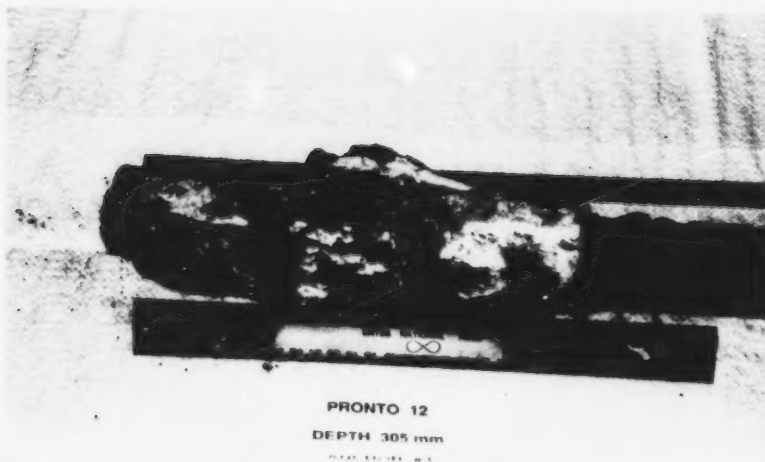


FIGURE 8
PRONTO 12 BULB

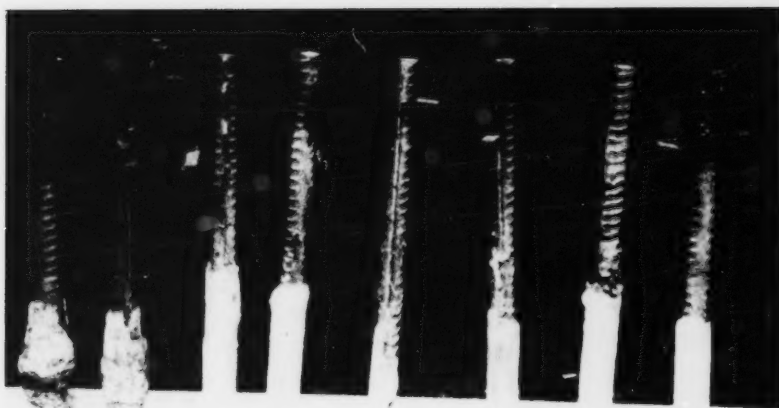
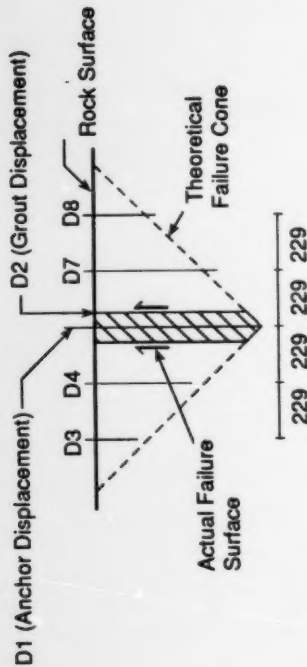


FIGURE 9
TYPICAL GROUT-TO-ROCK BOND FAILURES

KEY



NOTES:

- (i) Sketch not to scale.
- (ii) Telltales D3, D4 within theoretical rock failure cone (see also Figure 6).
- (iii) Telltales D7, D8 extend beyond theoretical rock failure cone (see also Figure 6).
- (iv) Total pullout was approximately 150 mm. Load data were not available beyond what is illustrated.

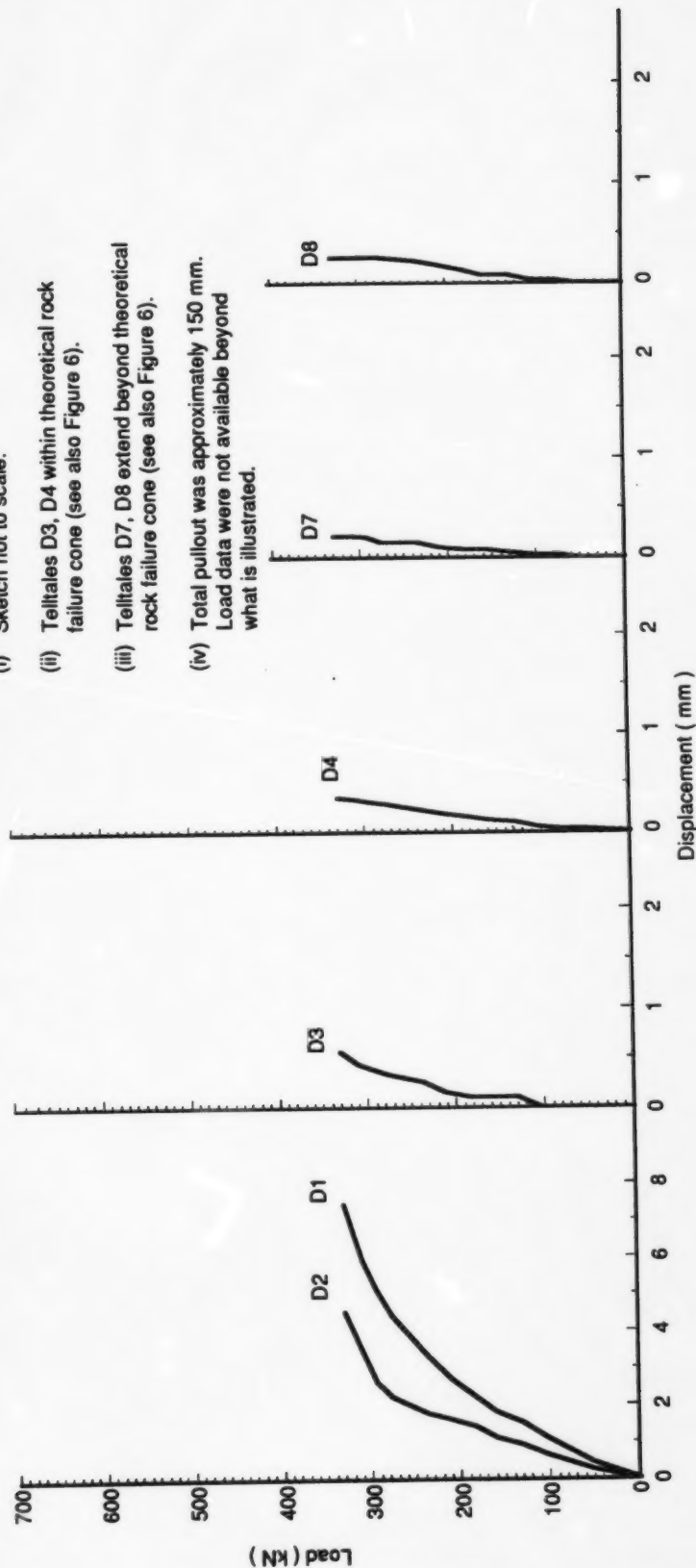
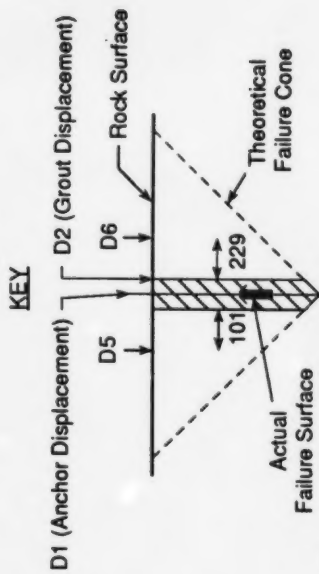


FIGURE 10
LOAD-DISPLACEMENT CURVES - TYPICAL GROUT-TO-ROCK BOND FAILURE
(ANCHOR 5 - LOKSET AT 305 mm EMBEDMENT)



- NOTES:**
- (i) Sketch not to scale.
 - (ii) D5, D6 placed on surface of rock.
 - (iii) Total pullout was approximately 150 mm. Load data were not available beyond what is illustrated.

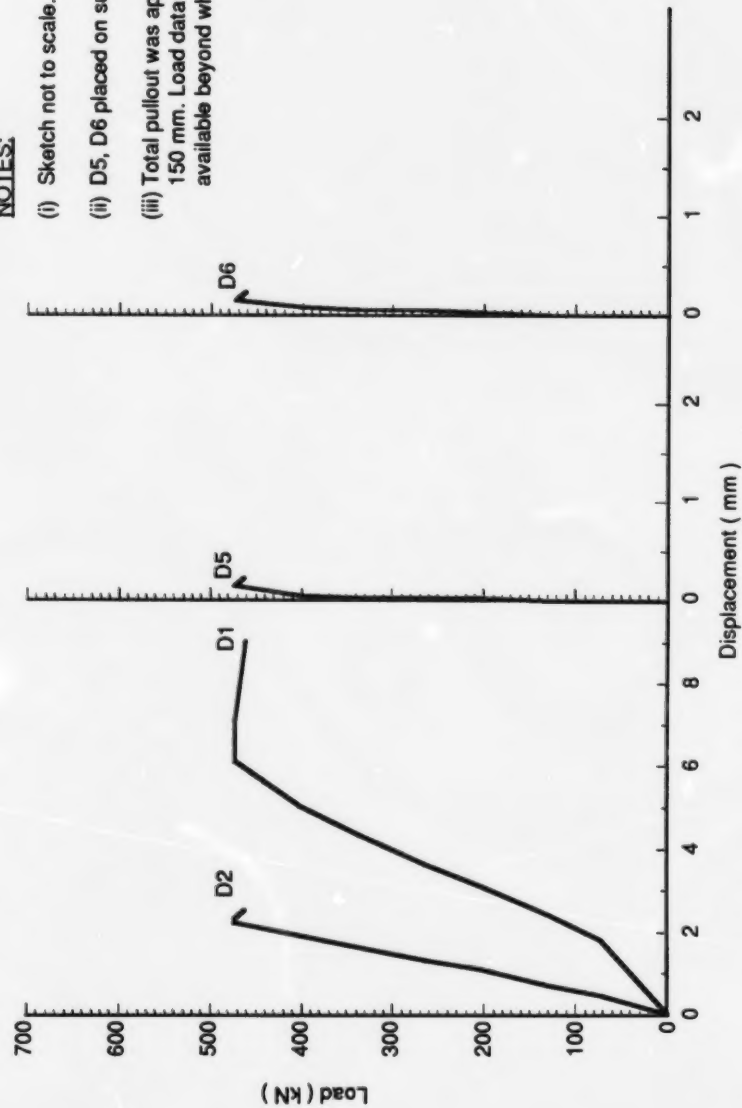
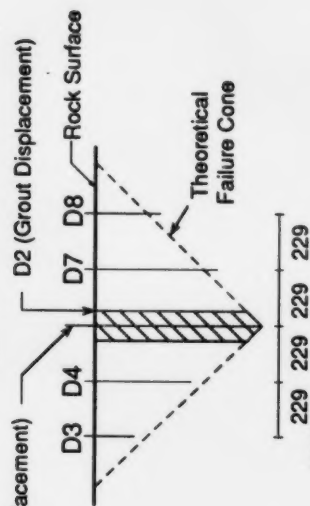


FIGURE 11

**LOAD-DISPLACEMENT CURVES - TYPICAL GROUT-TO-ROD BOND FAILURE
(ANCHOR 13 - CONCRESSIVE 2010 / 2020 AT 305 mm EMBEDMENT)**

KEY



NOTES:

- (i) Sketch not to scale.
- (ii) Telltales D3, D4 within theoretical rock failure cone (see also Figure 6).
- (iii) Telltales D7, D8 extend beyond theoretical rock failure cone (see also Figure 6).
- (iv) Total pullout was approximately 150 mm. Load data was not available beyond what is illustrated.

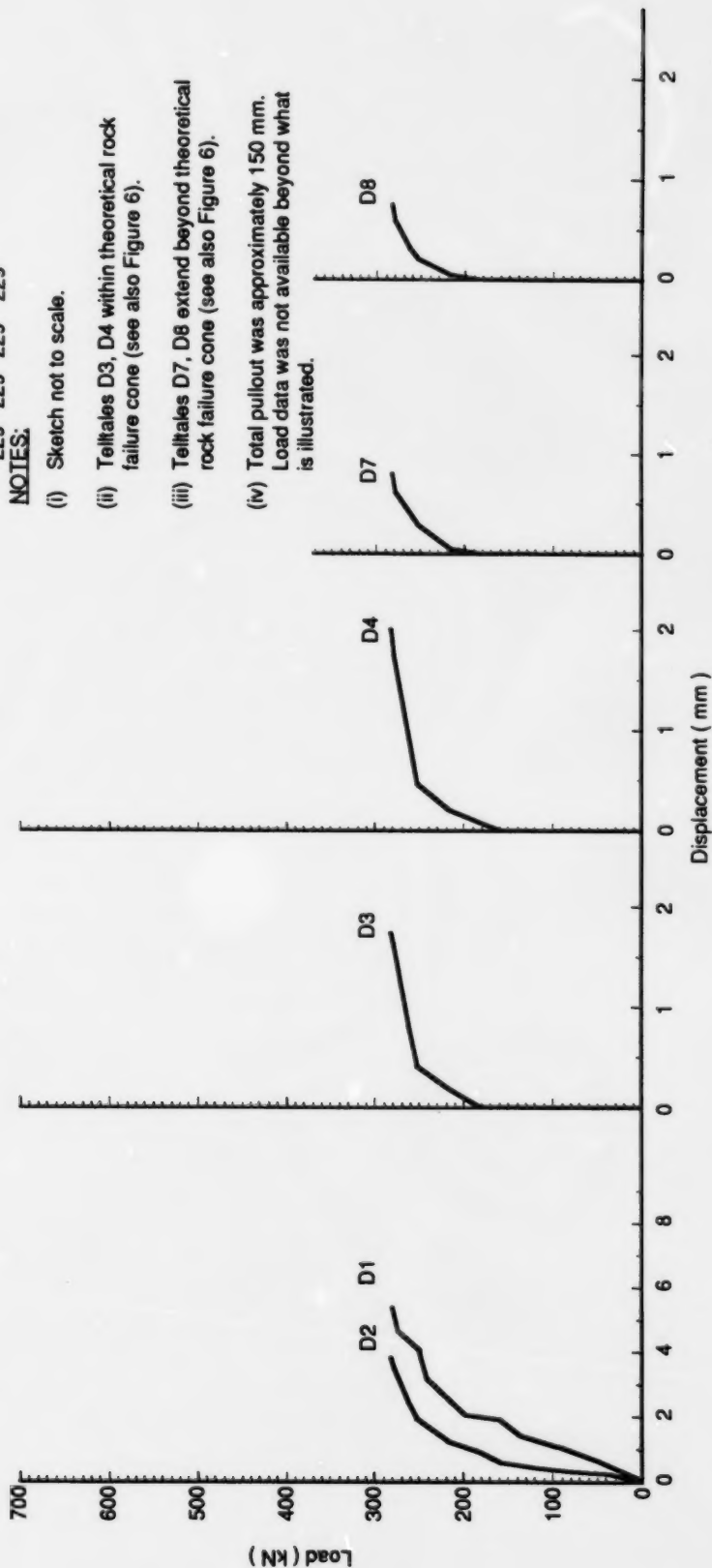


FIGURE 12

LOAD-DISPLACEMENT CURVES - TYPICAL ROCK UPLIFT FAILURE
(ANCHOR 1 - PRONTO 12 AT 305 mm EMBEDMENT)

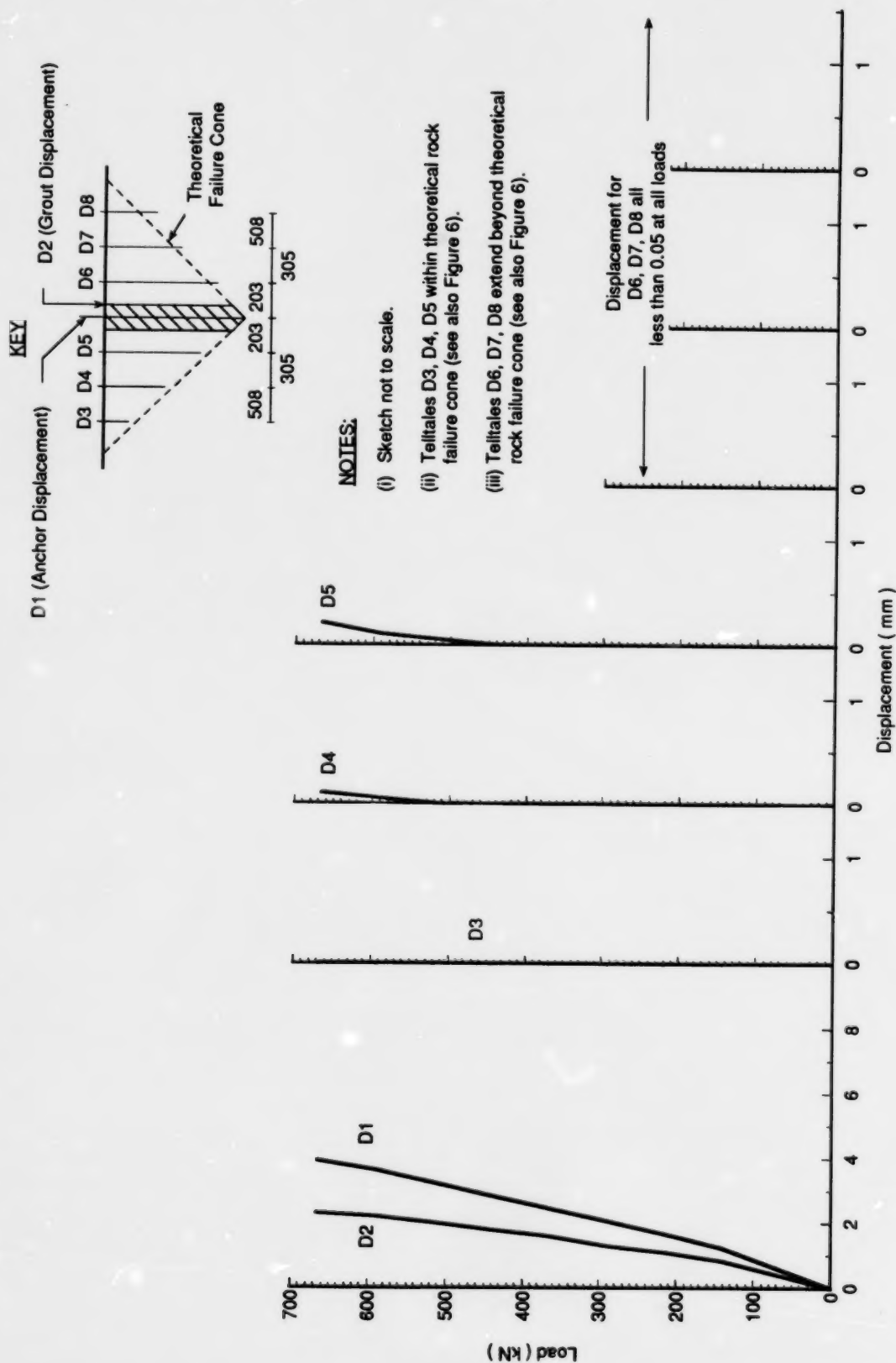


FIGURE 13

LOAD-DISPLACEMENT CURVES - TYPICAL OF NO FAILURE
(ANCHOR 37 - LT ANCHOR AT 915 mm EMBEDMENT)

APPENDIX A

Calculation of Grout-to-Rod Bond Failure Loads

A1 PURPOSE

The purpose of this appendix is to document the calculations for the grout-to-rod bond failure loads.

A2 VARIABLES

- a) Ultimate grout-to-rock bond stress: based on $11.5 \times \sqrt{f'_c}$

Product	28-day f'_c (psi)	Ultimate Stress (psi)
Pronto 12	12,130	1,266
Lokset	5,690	867
Anchortite 21-30 FS	11,290	1,222
LT Anchor Grout	12,720	1,297
Concressive 2010/2020	6,170	903
Type 10 Cement (w/c=0.40)	9,000	1,091

- b) Anchor rod diameter = 1-3/8 in.
c) Embedment depths = 12, 20, and 36 in.

A3 CALCULATED GROUT-TO-ROD FAILURE LOADS

Product	Failure Load (kips)		
	12" embedment	20" embedment	36" embedment
Pronto 12	66	109	197
Lokset	45	75	135
Anchortite 21-30 FS	63	106	190
LT Anchor Grout	67	112	202
Concressive 2010/2020	47	78	140
Type 10 Cement (w/c=0.40)	57	94	170

Note: The failure loads are reported in Imperial units as the original allowable stress formula was reported in Imperial units.

APPENDIX B

Calculation of Grout-to-Rock Bond Failure Loads

B1 PURPOSE

The purpose of this appendix is to document the calculations for the grout-to-rock bond failure loads.

B2 VARIABLES

- a) Ultimate grout-to-rock bond stress: based on $\frac{U.C.S.}{10}$
 where U.C.S. = unconfined compressive strength of the grout or rock.

Product	28-day f'c (psi)	Ultimate stress(1) (psi)
Pronto 12	12,130	1,213
Lokset	5,690	569
Anchortite 21-30 FS	11,290	1,129
LT Anchor Grout	12,720	1,272
Concressive 2010/2020	6,170	617
Type 10 cement (w/c=0.40)	9,000	900

Note: (1) The ultimate compressive strength of the rock was 13,055 psi. Therefore, the grout strength governed in all calculations.

- b) Hole Diameter: 2-1/4 in.
 c) Embedment depths: 12, 20, and 36 in.

B3 CALCULATED GROUT-TO-ROCK FAILURE LOADS

Product	Failure Load (kips)		
	12" embedment	20" embedment	36" embedment
Pronto 12	103	171	309
Lokset	48	80	145
Anchortite 21-30 FS	96	160	287
LT Anchor Grout	108	180	324
Concressive 2010/2020	52	87	157
Type 10 cement (w/c=0.40)	76	127	229

APPENDIX C

Pullout Results

C1 PURPOSE

The purpose of this appendix is to summarize the results for each individual anchor that was tested.

C2 RESULTS

The results are summarized in Tables C1, C2, C3 for the 305 mm (12 in.), 508 mm (20 in.) and 915 mm (36 in.) embedments, respectively.

TABLE C1
PULLOUT RESULTS FOR ANCHORS GROUTED TO A
NOMINAL EMBEDMENT OF 305 mm

ANCHOR I.D. (1)	PRODUCT	ACTUAL GROUTED LENGTH (mm)	FAILURE LOAD (kN)	FAILURE MODE (2)	REMARKS
1	PRONTO 12	241	293	R	- large bulb of grout approx. 83 mm dia. at midlength of grout column
2	PRONTO 12	267	259	R	- grout well bonded to anchor - large bulb of grout approx. 105 mm dia. 70 mm from top of grout column
3	PRONTO 12	254	183	R	- grout well bonded to anchor - large bulb of grout approx. 101 mm dia. 75 mm from top of grout column - grout well bonded to anchor
4	LOKSET	349	447	G/rock	- grout column generally uniform and smooth; no voids - bottom 62 mm of grout column failed at steel interface
5	LOKSET	305	342	G/rock	- grout well bonded to anchor - grout column generally uniform and smooth; no voids - 70 mm dia. bulb of grout at top of grout column
6a	LOKSET	298	290	G/rock	- grout well bonded to anchor - grout only on one side of anchor; possibility of voids in rock that led to bulb effect on the other side of the anchor
7	ANCHORTITE 21-30 FS	260	89	G/rock	- grout column generally uniform and smooth; no voids - grout well bonded to anchor
8	ANCHORTITE 21-30 FS	311	320	G/rock	- very poor rock bond - grout column generally uniform and smooth; no voids
9	ANCHORTITE 21-30 FS	273	400	G/rock	- grout well bonded to anchor - grout column generally uniform and smooth; no voids - grout well bonded to anchor
10	LT ANCHOR	324	632	G/rock	- grout column generally uniform and smooth; no voids - bottom 178 mm of grout column remained in hole - top 146 mm of grout well bonded to anchor
11	LT ANCHOR	324	670	G/rock	- grout column generally uniform and smooth; no voids - bottom 100 mm of grout column remained in hole - top 224 mm of grout well bonded to anchor
12	LT ANCHOR	324	632	G/rock	- grout column generally uniform and smooth; no voids - bottom 210 mm of grout column remained in hole - top 114 mm of grout well bonded to anchor

TABLE C1 (cont'd)
**PULLOUT RESULTS FOR ANCHORS GROUTED TO A
 NOMINAL EMBEDMENT OF 305 mm**

ANCHOR I.D. (1)	PRODUCT	ACTUAL GROUTED LENGTH (mm)	FAILURE LOAD (kN)	FAILURE MODE (2)	REMARKS
13	CONCRESSIVE 2010/2020	381	400	G/rod	- anchor pulled out of grout column - grouted length estimated by measuring non-rusted length of anchor - grout remained between deformations of anchor
14	CONCRESSIVE 2010/2020	330	534	G/rod	- same remarks as for anchor #13
15	CONCRESSIVE 2010/2020	286	467	G/rod	- same remarks as for anchor #13
A	TYPE 10 CEMENT	432	627	G/rod	- same remarks as for anchor #13
B	TYPE 10 CEMENT	356	734	G/rod	- same remarks as for anchor #13

(1) See Figure 2

(2) R = rock uplift

G/rock = grout-to-rock bond

G/rod = grout-to-rod bond

TABLE C2
PULLOUT RESULTS FOR ANCHORS GROUTED TO A
NOMINAL EMBEDMENT OF 508 mm

ANCHOR I.D. (1)	PRODUCT	ACTUAL GROUTED LENGTH (mm)	FAILURE LOAD (kN)	FAILURE MODE (2)	REMARKS
16	PRONTO 12	N/A	>734	none	- 5 minute hold at 667 kN followed by a 5 minute hold at 734 kN - 5 minute hold at 734 kN
17	PRONTO 12	N/A	>734	none	
18	PRONTO 12	N/A	>734	none	
19	LOKSET	N/A	>734	none	- 5 minute hold at 734 kN followed by 1 cycle of 0 to 734 kN - grout column generally uniform and smooth - grout well bonded to anchor - grout column generally uniform and smooth - grout well bonded to anchor
20	LOKSET	483	654	G/rock	
21	LOKSET	508	663	G/rock	
22	ANCHORTITE 21-30 FS	483	734	G/rock	- rock failed after the grout/rock bond had failed - grout column generally uniform and smooth - grout well bonded to anchor - grout column generally uniform and smooth - grout well bonded to anchor - 5 minute hold at 734 kN
23	ANCHORTITE 21-30 FS	533	667	G/rock	
24	ANCHORTITE 21-30 FS	N/A	>734	none	
25	LT ANCHOR	N/A	>734	none	- 5 minute hold at 734 kN followed by 4 cycles of 0 to 734 kN - 5 minute hold at 734 kN followed by 1 cycle of 0 to 734 kN - 5 minute hold at 734 kN followed by 1 cycle of 0 to 734 kN
26	LT ANCHOR	N/A	>734	none	
27	LT ANCHOR	N/A	>734	none	
28	CONCRESSIVE 2010/2020	N/A	>778	none	- 5 minute hold at 778 kN - 10 minute hold at 778 kN - 5 minute hold at 778 kN
29	CONCRESSIVE 2010/2020	N/A	>778	none	
30	CONCRESSIVE 2010/2020	N/A	>778	none	
E	TYPE 10 CEMENT	N/A	>734	none	- 5 minute hold at 734 kN
F	TYPE 10 CEMENT	N/A	>734	none	- 5 minute hold at 734 kN

(1) See Figure 2

(2) G/rock = grout-to-rock bond

TABLE C3
PULLOUT RESULTS FOR ANCHORS GROUTED TO A
NOMINAL EMBEDMENT OF 915 mm

ANCHOR I.D. (1)	PRODUCT	ACTUAL GROUTED LENGTH (mm)	FAILURE LOAD (kN)	FAILURE MODE (2)	REMARKS
31	PRONTO 12	N/A	>667	none	- 5 minute hold at 667 kN
32	PRONTO 12	N/A	>667	none	- 5 minute hold at 667 kN
33	LOKSET	N/A	>667	none	- 5 minute hold at 667 kN
34	LOKSET	N/A	>667	none	- 5 minute hold at 667 kN
35	ANCHORTITE 21-30 FS	N/A	>667	none	- 5 minute hold at 667 kN followed by 3 cycles of 0 to 667 kN
36	ANCHORTITE 21-30 FS	N/A	>667	none	- 5 minute hold at 667 kN
37	LT ANCHOR	N/A	>734	none	- 5 minute hold at 734 kN followed by 2 cycles of 0 to 734 kN
38	LT ANCHOR	N/A	>734	none	- 5 minute hold at 734 kN
39	CONCRESSIVE 2010/2020	N/A	>801	none	- 5 minute hold at 667 kN followed by a 5 minute hold at 734 kN followed by a 5 minute hold at 801 kN
40	CONCRESSIVE 2010/2020	902	801	G/rod	- after approx. 6 minute hold at 801 kN, the anchor pulled out of the grout column - grouted length estimated by measuring the non-rusted length of anchor - grout remained between deformations of anchor
C	TYPE 10 CEMENT	N/A	>734	none	- 5 minute hold at 734 kN
D	TYPE 10 CEMENT	N/A	>734	none	- 9 minute hold at 734 kN

(1) See Figure 2

(2) G/rod = grout-to-rod bond